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Trait anxiety is associated with reduced typicality asymmetry in fear generalization☆

Alex H.K. Wong [a,b,*], Tom Beckers [c,d]

[a] University of New South Wales Sydney, Sydney, NSW, Australia
[b] Department of Psychology (Biological Psychology, Clinical Psychology and Psychotherapy), University of Würzburg, Würzburg, Germany
[c] Centre for the Psychology of Learning and Experimental Psychopathology, Faculty of Psychology and Educational Sciences, KU Leuven, Leuven, Belgium
[d] Leuven Brain Institute, KU Leuven, Leuven, Belgium

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ABSTRACT

In fear conditioning, training with typical category exemplars has been shown to promote fear generalization to novel exemplars of the same category, whereas training with atypical category exemplars supports limited if any generalization to other category members, amounting to a typicality asymmetry in fear generalization. The present study sought to examine how trait anxiety bears on typicality asymmetry in fear generalization. Participants in one condition were presented with typical exemplars during fear acquisition and atypical exemplars of the same category in the subsequent generalization test (typical condition), whereas in the other group, atypical and typical exemplars were presented during fear acquisition and generalization test, respectively (atypical condition). We observed a typicality asymmetry in fear generalization in self-reported expectancy ratings in low trait anxious individuals only. High trait anxious individuals showed a similar degree of fear generalization in both conditions. The current results help illuminate why some individuals are at risk for exhibiting broad fear generalization after exposure to an aversive event.

Fear conditioning refers to the repeated pairing of a neutral stimulus (CS+) with an aversive unconditioned stimulus (US). As a result, the CS+ becomes a signal for threat and evokes conditioned fear. The process of an initially neutral CS coming to signal danger is conceptually related to the development of clinical fear in individuals with anxiety disorders (Watson & Rayner, 1920). Indeed, the fear conditioning paradigm is a well-validated laboratory model for examining the psychopathology of anxiety disorders (Mineka & Zinbarg, 2006; Vervliet & Raes, 2013).

Using the fear conditioning model, studies have uncovered maladaptive patterns of fear learning and expression in individuals with anxiety disorders (Duits et al., 2015; Lissek et al., 2005), including excessive fear generalization (Kaczkurkin et al., 2017; Lissek et al., 2010, 2014). Fear generalization refers to the spread of fear to novel objects or situations that resemble a fear-related CS+, despite these novel stimuli had never been directly paired with the US themselves. Excessive fear generalization provides a viable explanation for the maladaptive fear to a wide range of objects observed among individuals with anxiety disorders. According to traditional associative accounts, the generalization of conditioned fear is a direct function of the physical similarity between generalization stimuli (GSs) and the CS+ (Blough, 1975; Honig & Urcuioli, 1981; Mackintosh, 1974): The more perceptually dissimilar a GS is to the CS+, the weaker the generalized fear (i.e., generalization decrement). However, recent evidence suggests that not only perceptual features of a GS, but also higher-order conceptual relations between the CS+ and a GS affect the degree of generalization (e.g., Ahmed & Lovibond, 2018; Bennett, Vervoort, Boddez, Hermans, & Baeyens, 2015; Boddez, Bennett, van Esch, & Beckers, 2017; Shanks & Darby, 1998; Wong & Lovibond, 2017). Specifically, studies have shown that humans generalize their fear to novel stimuli that are conceptually related to the CS+ even in the absence of physical similarity. For instance, humans generalize fear to novel stimuli semantically related to the CS+ (e.g., Boyle, Dymond & Hermans, 2016; Maltzman, Langdon, Pendery, & Wolff, 1977), symbolically related to the CS+ (e.g., Dymond, Schlund, Roche, & Whelan, 2014, 2011; Vervoort, Vervliet, Bennett, & Baeyens, 2014), or categorically related to the CS+ (e.g., Dunsmoor, Martin, & LaBar, 2012; Lee, Lovibond, & Hayes, 2019; Wong & Pittig, 2020).

☆ Data is available through the Open Science Framework (https://osf.io/az2tw/).

* Corresponding author. University of New South Wales Sydney, Sydney, NSW, Australia.
E-mail address: hon.wong@uni-wuerzburg.de (A.H.K. Wong).

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One higher-order factor that further modulates category generalization is typicality. Using a category fear conditioning framework, Dunsmoor and Murphy (2014) found that individuals trained with atypical exemplars, that is, exemplars that are less representative of a given category (e.g., armadillo as a mammal) showed a very limited degree of fear generalization to novel exemplars of the same category. In contrast, individuals trained with typical exemplars (exemplars that are considered very representative of their category; e.g., bear as a mammal) showed strong fear generalization to novel exemplars of the same category. The authors suggested that being trained with typical exemplars may have promoted the attribution of US occurrence to category membership (formation of a category membership - US association), resulting in novel exemplars of the same category triggering strong generalized fear. In contrast, training with atypical exemplars may have prevented the attribution of US occurrence to category membership, promoting instead the formation of individual exemplar - US associations. As a result, fear generalization to novel exemplars of the same category is far more limited. In sum, an asymmetry in fear generalization between typical and atypical category members is observed.

Although the level of typicality of the training exemplars affects the degree of fear generalization, it may do so to a lesser extent in individuals with high trait anxiety. Trait anxiety is widely regarded as a vulnerability factor for the development of anxiety disorders (e.g., Chambers, Power, & Durham, 2004; Gershuny & Sher, 1998; Jorm et al., 2000). High trait anxious individuals, like patients with anxiety disorders, also show maladaptive patterns of fear learning, for instance, impaired fear inhibition (e.g., Boddez et al., 2012; Gazendam, Kamphuis, & Kindt, 2013; Haaker et al., 2015) and resistance to extinction (e.g., Barrett & Armony, 2009; Dibbets, van den Broek, & Evers, 2014; Wong & Lovibond, 2020a). Effects of trait anxiety on fear learning are particularly likely to be observed in a 'weak' fear learning situation, where the status of stimuli is inherently ambiguous (Beckers, Krypotos, Boddez, Effting, & Kindt, 2013; Lissek, Pine, & Grillon, 2006).

Given that training with atypical exemplars is thought to restrict fear learning to the specific training exemplars, the threat value of novel exemplars presented at test will be ambiguous, as their US predictiveness is relatively unclear, yielding a 'weak' situation. Therefore, we hypothesized that high trait anxious individuals trained with atypical exemplars would show greater generalization to novel exemplars of the same category than low trait anxious individuals. In contrast, to the extent that training with typical exemplars indeed leads to the association of category membership with the US, the threat value of novel exemplars will be relatively unambiguous. Therefore, we expected less if any trait anxiety differences in fear generalization in individuals trained with typical exemplars as CS+. In preliminary support of the predictions above, Wong and Lovibond (2020b) found no trait anxiety differences in fear generalization to novel exemplars that clearly belonged to the CS+ category, but greater generalized fear in high than low trait anxious individuals to novel exemplars that simultaneously belonged to both the CS+ and safe (CS-) categories (thus yielding heightened threat ambiguity).

The predictions above provide an additional potential explanation for why certain individuals are more likely to develop clinical anxiety after trauma exposure. While low trait anxious individuals are less likely to generalize from an atypical traumatic event compared to a typical traumatic event, high trait anxious individuals might generalize fear similarly from both atypical and typical trauma exposures, thus increasing the chances of developing a full-blown anxiety disorder. This study sought to provide evidence for this distinct explanation of high trait anxious individuals' vulnerability to developing clinical anxiety.

To examine the effects of trait anxiety and typicality (and the interaction of both) on fear generalization, we adopted the fear conditioning procedure developed by Dunsmoor and Murphy (2014), using a 2 by 2 (trait anxiety by typicality) factorial design. In the atypical condition, participants were trained with atypical CS+ exemplars and then presented with novel typical exemplars of the same category at test, and vice versa for participants in the typical condition. Both typical and atypical conditions were trained with CS- exemplars of intermediate typicality and presented with novel exemplars of the same category of intermediate typicality at test as well. Fear learning and generalization were measured through US expectancy ratings, skin conductance responses (SCRs) and fear potentiated startle (FPS) responses.

1. Method

1.1. Participants

Psychology undergraduates from KU Leuven were recruited as participants and received partial research credit for participation. Participants were pre-screened using the Dutch version of the DASS-21 (de Beurs, Van Dyck, Marquenie, Lange, & Blonk, 2001; Lovibond & Lovibond, 1995). The DASS-21 is a short version of the original DASS (Depression Anxiety Stress Scale), which validly measures and discriminates between depression, anxiety and stress/tension (Antony, Bieling, Cox, Enns, & Swinson, 1998; Brown, Chorpita, Korotitsch, & Barlow, 1997; Henry & Crawford, 2005; Lovibond, 1998). Individuals with a DASS-Anxiety score of 14 or above were recruited as high anxious (HA) participants while those with a DASS-Anxiety score of 4 or below were recruited as low anxious (LA) participants. Forty-seven HA and 49 LA participants were recruited respectively, resulting in a total of 96 participants. Among HA participants, 23 were randomly assigned to the atypical condition whereas 24 were randomly assigned to the typical condition. Likewise, 24 LA participants were randomly assigned to the atypical condition and 25 were randomly assigned to the typical condition. This study was approved by the KU Leuven Social and Societal Ethics Committee.

1.2. Apparatus and materials

Twelve greyscale images, each from two categories, birds and mammals, presented on a black background, were used as exemplars. They had been rated for typicality of category membership by 23 separate participants in a pilot study, on a Likert scale ranging from 1 (not at all typical) to 7 (highly typical). Atypical category members had a mean rating of 2.7 (SD = 1.6), typical category members had a mean rating of 6.6 (SD = 0.8), and intermediate category members had a mean rating of 4.7 (SD = 1.7). Table 1 lists the birds and mammals whose images were presented as stimuli. All visual stimuli were generated and presented with Affect4.0 software (Spruyt, Clarysse, Vansteenwegen, Baeyens, & Hermans, 2009).

The aversive US was a 2-ms electric stimulus generated by a Digitimer DS7A stimulator. The electric stimulus was delivered via two electrodes attached to the wrist of participants' non-dominant hand. Skin conductance was measured via two disposable Ag/AgCl electrodes attached to the palm of the same hand, at a sampling rate of 1000 Hz. Fear-potentiated startle was measured via startle blink electromyography (EMG), at a sampling rate of 1000 Hz. Two Ag/AgCl electrodes were attached to participants' orbicularis oculi muscle under the right eye, while a ground electrode was attached to the forehead (Blumenthal et al., 2005). The acoustic startle probe was a 40-ms white noise of 100 dB delivered via headphones.

Table 1
Bird and mammal exemplars used in the current study.

Typicality	Birds	Mammals
Typical	Hummingbird, pigeon, sparrow	Bear, cow, gorilla
Atypical	Cassowary, emu, penguin	Bat, platypus, seal
Intermediate	Duck, flamingo, kiwi, peahen, swan, turkey	Alpaca, camel, dolphin, otter, rat, sloth

2. Procedure

After the participants provided written informed consent, electrodes and the startle probe headphone were attached. Participants were led through a work-up procedure in which they selected a level of electric stimulus that was 'definitely uncomfortable but not painful'. The experiment consisted of 3 phases: Startle habituation, fear acquisition and the generalization test (see Table 2).

Startle habituation. Participants were informed that acoustic white noise would be delivered via the headphones throughout the experiment. They were told that the purpose of this phase was for them to adapt to the noise. Ten startle probes were then delivered with an inter-trial interval (ITI) of 15 s.

Fear acquisition. Participants were informed that different pictures would appear on the screen, which might or might not be followed by an electric stimulus. They were asked to learn the relationship between the pictures and the electric stimulus (Mertens, Boddez, Krypotos, & Engelhard, 2020). Participants were instructed to indicate their expectancy of the electric stimulus US using a visual-analogue scale (VAS) during the picture presentations. The VAS ranged from 0 to 100, in which 0 indicated certain of US absence and 100 indicated certain of US occurrence. The fear acquisition phase was divided into 3 blocks. In each block, 3 different exemplars from one category (e.g., mammals) served as the CS+ while 3 different exemplars from the other category (e.g., birds) served as the CS-. Each CS was presented once, resulting in 6 CS trials per block. Each CS+ exemplar was reinforced 2 out of 3 trials (67% reinforcement rate), whereas the CS- exemplars were never reinforced. The categories that served as CS+ and CS- were counterbalanced across participants. Importantly, the CS+s were atypical exemplars (e.g., bat) in the atypical condition and were typical exemplars in the typical condition (e.g., bear). The CS-s were always exemplars of intermediate typicality (e.g., alpaca). Each CS was presented for 8 s, at the centre of the screen, with the expectancy VAS located below the CS. An acoustic startle probe was delivered on every CS trial, 7 s after CS onset. If scheduled, the electric stimulus US was presented immediately after CS+ offset. An additional 9 noise alone (NA) trials (3 per block) were presented in which only the startle probe was delivered. All CS and NA trials were followed by an ITI of 10–15 s. The presentation order was pseudo-randomized such that the same trial type never appeared more than twice in a row.

Generalization test. The test phase followed the fear acquisition phase seamlessly. Similar to the previous phase, the generalization test phase was divided into 3 blocks: 3 novel exemplars from the CS+ category (GS+) and 3 novel exemplars from the CS- category (GS-) were presented once each per block, resulting in a total of 18 GS trials in the test. The atypical condition received typical GS+ exemplars whereas the typical condition received atypical GS+ exemplars. Both conditions were presented with GS- exemplars of intermediate typicality. An additional 9 NA trials were also presented. The trial structure followed fear acquisition with the exception that no electric stimulus USs were delivered.

Table 2
Design of current study

Startle habituation	Fear acquisition	Generalization test
NA (10)	CS+ (6) CS+* (3) CS- (9) NA (9)	GS+ (9) GS- (9) NA (9)

CS+ indicates exemplars reinforced with an electric stimulus; CS- indicates exemplars never reinforced with an electric stimulus; * indicates non-reinforced CS+ trials; NA indicates startle probe alone trials; GS+ indicates exemplars of the same category as CS+; GS- indicates stimuli of the same category as CS-; numbers in brackets indicate the number of trials of that type in each phase. No exemplars were reinforced with an electric stimulus in the generalization test.

2.1. Scoring and analysis

Raw SCR and FPS data were processed using the Psychophysiological Analysis (PSPHA) software package (De Clercq, Verschuere, De Vlieger, & Crombez, 2006). The SCR for each trial was obtained by subtracting the averaged skin conductance level during 2 s prior to CS onset from the maximum response within 7 s after CS onset (see Pineles, Orr, & Orr, 2009). Negative SCRs were scored as zero. All SCRs were then square-root transformed to reduce skewness (Boucsein et al., 2012). The FPS magnitude was obtained by subtracting the mean value during the first 20 ms after probe onset from the peak magnitude in a 21–200 ms period after probe onset. The resulting FPS data were then z-transformed within participants.

All data were analysed by a set of planned orthogonal contrasts, using a multivariate repeated measures framework (O'Brien & Kaiser, 1985). Unlike an omnibus ANOVA, planned contrasts compare between specific levels of factors to test for a priori hypotheses, which arguably provide more statistical power than an omnibus ANOVA (Baguley, 2012; Bird, 2004). Planned contrasts were used to compare the two between-subjects factors – Anxiety (HA vs LA) and Typicality (atypical vs typical) – and the interaction between them across fear acquisition and the generalization test. Three within-subjects repeated contrasts were employed for the fear acquisition data. First, the averaged responding to the CS+ was compared to the CS- (main effect of Stimulus type). Second, the change in the level of responses across acquisition was captured by a linear trend repeated contrast across blocks (main effect Block). Third, the interaction of these two contrasts (Stimulus type * Block interaction) examined the development of differential responding to the CSs. For the generalization test data, we analysed the first test block only to minimize the effect of extinction learning. A within-subjects repeated measures contrast compared responding between GS+ and GS- (main effect of Stimulus type), to assess the degree of fear generalization. All between-within subjects interactions were then tested to evaluate the effect of trait anxiety and typicality on fear acquisition and generalization.

3. Results

Statistical analyses were restricted to participants who demonstrated differential conditioning and awareness of the CS-US contingencies (see Lovibond & Shanks, 2002). These two criteria were defined by higher averaged expectancy ratings for the CS+ than to the CS- in the last acquisition block (i.e., the last 3 trials of CS+ and the last 3 trials of CS-). A total of 8 participants were excluded based on this criterion.[1] This left 41 participants in the atypical condition (21 HA and 20 LA individuals) and 47 participants in the typical condition (23 HA and 24 LA individuals).

Averaged across typicality conditions, the mean DASS-Anxiety scores for HA individuals (mean = 17.7) were significantly higher than the DASS-Anxiety scores for LA individuals (mean = 2.4), $F(1,84) = 645.03$, $p < .001$, $\eta_p^2 = 0.88$. No differences in age, sex and US intensity were detected between conditions (see Table 3).

3.1. Acquisition

Fig. 1A–B show the US expectancy ratings across fear acquisition. Averaged across Anxiety, Typicality and Block, ratings for the CS+ exemplars were significantly higher than for the CS- exemplars, yielding a main effect of Stimulus type, $F(1,84) = 318.88$, $p < .001$, $\eta_p^2 = 0.79$. This differential rating to the CS exemplars emerged over the course of acquisition, as evidenced by a significant interaction between Stimulus type and Block, $F(1,84) = 119.69$, $p < .001$, $\eta_p^2 = 0.59$. Importantly, no

[1] Analyses including all participants yielded similar results (see Supplementary Materials for the analyses).

Table 3
Demographic data: Means (and standard deviations).

	Atypical condition		Typical condition		F or $\chi 2$	*p*
	HA (n = 21)	LA (n = 20)	HA (n = 23)	LA (n = 24)		
Age	18.52 (1.21)	18.20 (.52)	18.52 (1.53)	18.13 (.45)	.98	*.437*
Sex (Female)	19 (90.48%)	17 (85.00%)	21 (91.30%)	23 (95.83%)	1.56	*.669*
US intensity (mA)	5.45 (2.25)	4.23 (1.24)	4.63 (2.11)	5.73 (2.87)	2.15	*.100*
DASS-A	19.05 (3.83)	2.60 (1.85)	16.26 (2.85)	2.08 (1.61)	645.03	*<.001*

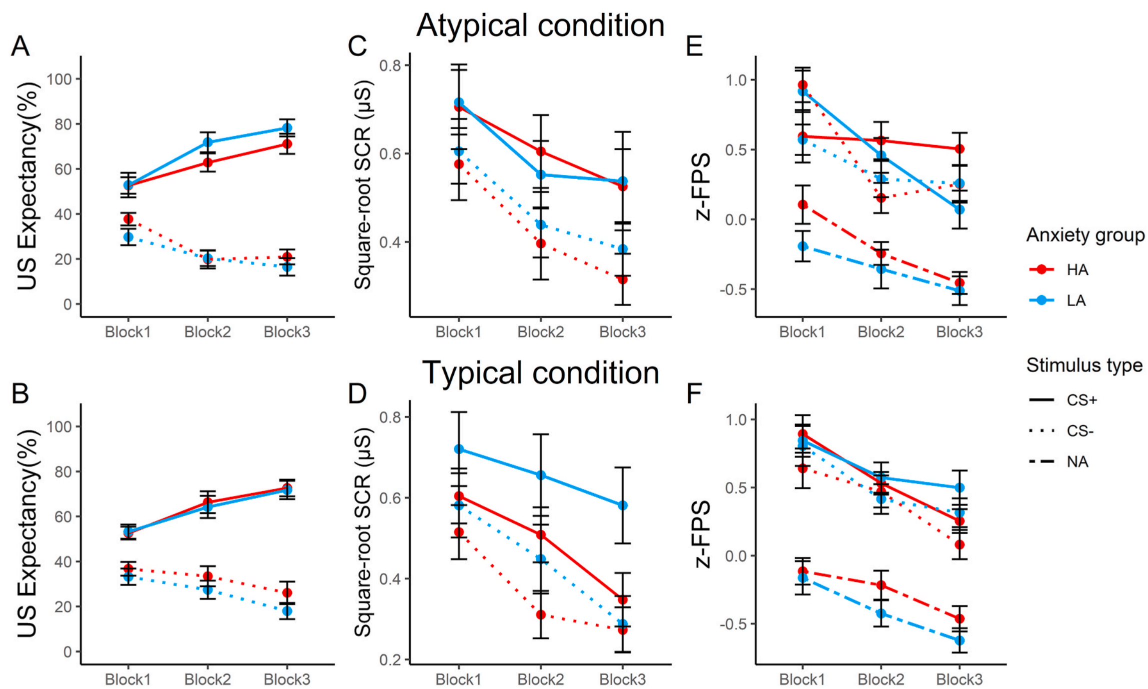

Fig. 1. Top panel: Mean US expectancy ratings (A), mean square-root SCR (C) and mean z-transformed FPS responses (E) of participants in the atypical condition during fear acquisition. Bottom panel: Mean US expectancy ratings (B), mean square-root SCR (D) and mean z-transformed FPS responses (F) of participants in the typical condition during fear acquisition. CS+ indicates reinforced categorical exemplars; CS- indicates non-reinforced categorical exemplars; NA indicates noise alone trials. HA indicates high trait anxious individuals; LA indicates low trait anxious individuals. Error bars indicate the standard error of the mean.

interactions involving Anxiety and Typicality reached significance (highest $F = 2.97$, $p = .088$), suggesting no major differences in fear acquisition between anxiety groups and typicality conditions.

Fig. 1C–D show the square-root SCRs across acquisition. Similar to the US expectancy measure, mean responding to the CS+ was higher than to the CS- averaged across Anxiety, Typicality and Block, resulting in a significant main effect of Stimulus type, $F(1,84) = 65.35$, $p < .001$, $\eta_p^2 = 0.44$. Differential SCR did not increase significantly across blocks, $F(1,84) = 1.89$, $p = .173$, $\eta_p^2 = 0.02$. Instead, responding to the CSs decreased across acquisition, presumably due to habituation. Differential responding to the CSs was descriptively larger in the HA typical condition than in the other conditions, but the 3-way interaction between Stimulus type, Anxiety and Typicality did not reach significance, $F(1,84) = 3.53$, $p = .064$, $\eta_p^2 = 0.04$. No other interactions involving Anxiety and Typicality reached significance (highest $F = 1.17$, $p = .283$). Considering the general decrease in SCRs and a lack of increased differential SCRs to the CSs across acquisition (i.e., a smaller decrease in SCRs to the CS+ than to the CS-), we carried out an additional analysis comparing SCRs to the CSs on the last acquisition block. Averaged across Anxiety, Condition and Block, SCRs to the CS+ were significantly stronger than the CS- on the last block, $F(1,84) = 38.73$, $p < .001$, $\eta_p^2 = 0.32$, confirming stronger acquisition of SCRs to the CS+ than the CS-.

The FPS data showed a relatively unclear pattern (Fig. 1E–F). As a check, averaged startle responding was stronger for the CSs than on baseline NA trials, averaged across Anxiety, Typicality and Block, $F(1,84) = 291.87$, $p < .001$, $\eta_p^2 = 0.78$. There were no anxiety nor typicality differences in baseline responding and in responding to the CSs (highest $F = 2.75$, $p = .101$). Like for the other measures, responses were stronger on the CS+ than on the CS- trials, averaged across anxiety groups, typicality conditions and blocks, resulting in a main effect of Stimulus type, $F(1,84) = 5.23$, $p = .025$, $\eta_p^2 = 0.06$. Similar to the SCR data, differential FPS responding did not increase across blocks, $F(1,84) = 0.086$, $p = .770$, $\eta_p^2 < 0.01$. Surprisingly, while participants showed a similar decrease in responding to the CS- across conditions, the LA atypical condition showed a larger decrease in responding to the CS+ over the acquisition phase than the other three conditions. This resulted in a significant 4-way interaction between Stimulus type, Anxiety, Typicality and Block, $F(1,84) = 7.45$, $p = .008$, $\eta_p^2 = 0.08$. No other interactions involving Anxiety and Typicality reached significance (highest $F = 3.40$, $p = .069$). Similar to the SCR data, we carried out an additional analysis comparing responding to the CSs on the last acquisition block. Averaged across Anxiety, Typicality and Block, although responding was stronger to the CS+ than the CS-, this difference did not reach significance, $F(1,84) = 1.61$, $p = .209$, $\eta_p^2 = 0.02$. Given that acquisition of differential FPS responding was not established, we did not include the FPS data in the generalization test (see Supplementary Materials for the analysis of FPS in test).

In sum, participants acquired differential responding to the CSs in the US expectancy and SCR measures (i.e., stronger responding to the CS+ than the CS-), but not in the FPS measure. Neither trait anxiety nor typicality had any effect on the acquisition of US expectancy and SCR to the CSs.

3.2. Generalization test

Fig. 2A and B show the US expectancy ratings in the first block of the generalization test. Only the critical interactions of interest were reported. Crucially, we observed a significant 3-way interaction between Anxiety, Typicality and Stimulus type, $F(1,84) = 5.88$, $p = .017$, $\eta_p^2 = 0.07$. This pattern suggests that the heightened US expectancy ratings in HA individuals were rather isolated to the GS+ in the atypical condition. Follow-up analyses confirmed that in the atypical condition, HA individuals showed higher US expectancy ratings for the GS+ than their LA counterparts, whereas both HA and LA individuals showed similar ratings for the GS-, resulting in a significant interaction between Anxiety and Stimulus type, $F(1,39) = 11.52$, $p = .002$, $\eta_p^2 = 0.23$. Additional simple analyses further confirmed that in the atypical condition, HA individuals showed higher ratings for the GS+ than the LA individuals, $F(1,39) = 38.97$, $p < .001$, $\eta_p^2 = 0.50$, whereas there was no evidence for anxiety differences in expectancy ratings for the GS-, $F(1,39) = 0.21$, $p = .651$, $\eta_p^2 < 0.01$. In contrast, in the typical condition, the interaction between Anxiety and Stimulus type did not reach significance, $F(1,45) = 0.02$, $p = .878$, $\eta_p^2 < 0.01$, suggesting no evidence for any trait anxiety differences in US expectancy ratings for either the GS+ or the GS-. This set of analyses suggests that trait anxiety was associated with enhanced fear generalization to the GS+, but only in the atypical condition.

To further examine the dynamics between the effects of trait anxiety and typicality on fear generalization, we examined the effect of typicality in each anxiety group. Among HA individuals, there was no evidence for any typicality differences on ratings for the GSs, given the interaction between Typicality and Stimulus type did not reach significance, $F(1,42) = 1.82$, $p = .184$, $\eta_p^2 = 0.04$. In the LA groups, the atypical condition showed lower expectancy ratings for the GS+ than the typical condition, whereas both conditions exhibited similar expectancy ratings for the GS-, leading to a significant interaction between Typicality and Stimulus type, $F(1,42) = 4.36$, $p = .043$, $\eta_p^2 = 0.09$. Follow-up simple analyses confirmed that the LA atypical condition showed significantly lower expectancy ratings for the GS+ compared to the LA typical condition, $F(1,42) = 15.97$, $p < .001$, $\eta_p^2 = 0.28$, whereas there was no evidence for any typicality differences in expectancy ratings for the GS-, $F(1,42) = 0.08$, $p = .778$, $\eta_p^2 < 0.01$. This set of analyses suggest that typicality asymmetry was only observed in LA individuals.

The SCR measure showed a rather unclear pattern (Fig. 2C & D). Surprisingly, no main effect of Stimulus type was obtained, $F(1,84) = 0.43$, $p = .516$, $\eta_p^2 < 0.01$, suggesting that responding to the GS+ was not stronger than the GS-. No other main effects nor interactions reached significance (highest $F = 2.48$, $p = .119$).

Some exemplars of one category in the generalization test may have borne similarities with test exemplars of the other category. For instance, bats have wings, which is a shared physical feature with bird exemplars, whereas some bird exemplars (e.g., cassowary, penguin) have plumage (i.e., a layer of feathers) perceptually similar to the fur of mammals. These shared features between categories might have confounded the findings in the generalization test. Therefore, we compared responding in the first block of the generalization test between the counterbalancing conditions in each anxiety group and typicality condition, for both US expectancy ratings and SCRs. There was no evidence that these similar features between the two categories affected either the US expectancy data (highest $F = 1.73$, $p = .205$) or SCRs (highest $F = 2.31$, $p = .143$) in the generalization test. This suggests that the similar features between categories did not confound the current findings.

In sum, fear was generalized selectively to the GS+, as evidenced in the US expectancy, but not in the SCRs. No trait anxiety nor typicality effect on generalization was observed in the SCRs. However, a clear effect of typicality was observed in the US expectancy. Crucially, this effect of typicality was greatly attenuated in high trait anxious individuals.

4. Discussion

Using a differential fear conditioning procedure with exemplars from two categories, the current study sought to examine how trait anxiety shapes typicality asymmetry in fear generalization. We will discuss our three major observations below.

First, we found that conditioned fear selectively generalized to novel exemplars that belonged to the trained CS+ category in the self-reported expectancy ratings. This replicates past studies that observed transfer of learnt fear to novel stimuli conceptually related to the CS+ after fear conditioning (e.g., Dunsmoor et al., 2012; Vervoort et al., 2014; Wong &

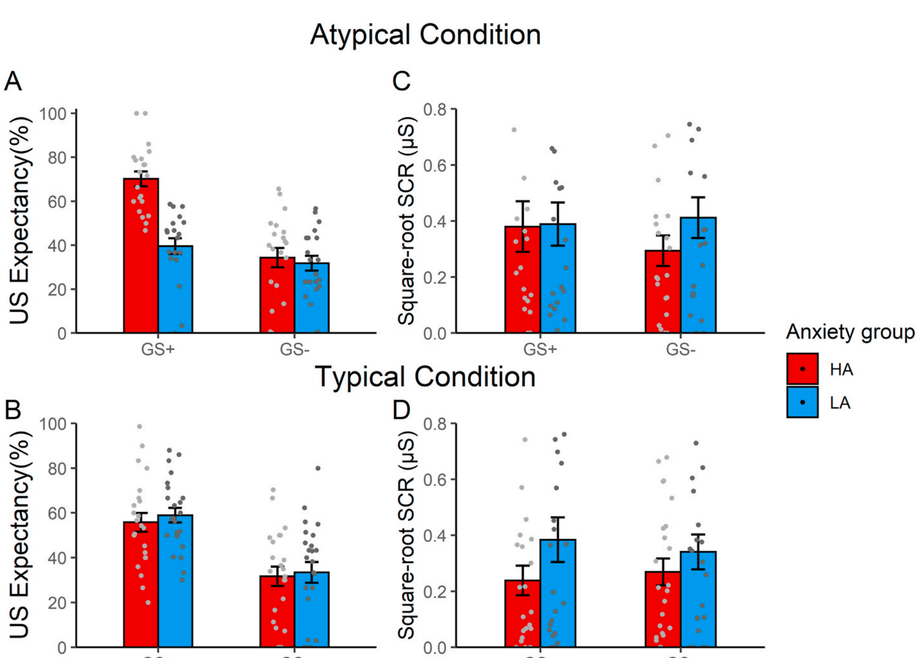

Fig. 2. Top panel: Mean US expectancy ratings (A) and mean square-root SCR (C) of individuals in the atypical condition during the first block of the generalization test. Bottom panel: Mean US expectancy ratings (B) and mean square-root SCR (D) of individuals in the typical condition during the first block of the generalization test. GS+ indicates novel exemplars of the CS+ category; GS- indicates novel exemplars of the CS- category. HA indicates high trait anxious individuals; LA indicates low trait anxious individuals. Gray dots depict the averaged responding in the first test block per participant. Error bars indicate the standard error of the mean.

Lovibond, 2020b). The capability to generalize beyond perceptual features permits the spread of fear to a wide range of objects or situations that do not physically resemble the fear-related object (Dymonds et al., 2015).

Second, differences in fear generalization as a function of trait anxiety were only observed in the atypical condition (i.e., when probing generalization from atypical to typical exemplars, constituting a 'weak' situation) and not in the typical condition. This interactive effect of trait anxiety and typicality on generalization was observed in US expectancy only, not in the SCR measure. The attenuated effect of trait anxiety on typicality asymmetry was presumably due to different attributions to US occurrence between typicality conditions. As discussed previously, training with atypical exemplars may have promoted the attribution of US occurrence to the individual exemplars instead of to the category membership (Dunsmoor & Murphy, 2014). As a result, participants might be unable to confidently judge the US predictiveness of the novel test exemplars based on their category membership, hence increasing threat ambiguity. Consequently, high trait anxious individuals showed elevated threat appraisal to the test exemplars, leading to stronger fear generalization than for their low anxious counterparts.

Although there was no difference in fear acquisition between typicality conditions, this does not preclude the possibility of between-conditions attributions of US occurrence to a higher-order categorical level or to an individual exemplar association. In other words, it might be possible that under the current conditions (e.g., with adequate training trials), participants who had learnt a category membership – US association and those who had learnt an individual exemplar – US association expressed similar levels of fear acquisition. The finding that high trait anxious individuals showed stronger fear generalization than their low trait anxious counterparts under conditions of threat ambiguity aligns with our past work (Wong & Lovibond, 2018, 2020b). Furthermore, the current work is consistent with past fear conditioning studies that observed a bias in threat appraisal in the presence of threat ambiguity in high anxious individuals (e.g., Baas, van Ooijen, Goudriaan, & Kenemans, 2008; Boddez et al., 2012; Chan & Lovibond, 1996). Using a blocking procedure, Boddez et al. (2012) found a positive correlation between US expectancy ratings to a blocked stimulus and trait anxiety. Given that the blocked stimulus was never presented alone, its predictiveness of the US was unclear, rendering its threat value ambiguous. In other words, anxious individuals showed elevated threat appraisal to a stimulus with ambiguous threat value. In a similar vein, anxious individuals who were unaware of the CS-US contingency (Chan & Lovibond, 1996) or the Context–CS–US contingency (Baas et al., 2008) showed elevated fear responding to a safety stimulus. Given that unaware individuals did not know which stimulus predicts the US, this effectively rendered the task situation ambiguous for them.

Third, we found the typicality asymmetry in fear generalization, reported earlier (Dunsmoor & Murphy, 2014), to be restricted to low trait anxious individuals. In a broader clinical context, typicality asymmetry in fear generalization could relate to the breadth of fear generalization after either typical or atypical trauma exposure. The current results suggest that while low trait anxious individuals show weaker fear generalization after an atypical trauma exposure compared to a typical trauma exposure, high trait anxious individuals exhibit similar levels of fear generalization following either typical or atypical traumatic events. An atypical trauma exposure could be traumatic events that are unusual and uncommon (see also Dymond, Dunsmoor, Vervliet, Roche, & Hermans, 2015), for instance, a rail accident. A train crash survivor with low trait anxiety may confine fear to rail travel but show limited generalization of fear to other forms of transport. High trait anxious individuals, on the other hand, may excessively generalize fear from this atypical traumatic rail travel experience to other modes of transport, increasing the likelihood of developing clinical anxiety. Therefore, the current results suggest an additional, distinct explanation for high trait anxious individuals' vulnerability to developing clinical anxiety.

One limitation of the current study was that most of the findings were obtained in US expectancy only and not corroborated by physiological measures. This apparent dissociation in the effects of typicality and trait anxiety (and their interaction) between verbal and physiological measure could be partially explained by reference to the three-system model of anxiety (Frijda, 1986; Lang, Bradley, & Cuthbert, 1998). This model proposes that fear can be acquired and expressed via three independent systems, including the report of subjective experience and cognitions, physiological activity, and overt behaviour. These three systems are known to work partially independently, giving way to the observation of different levels of responding across measures to the same stimulus (Mauss & Robinson, 2009). However, the three-system model does not give a clear prediction for when and why fear responding will diverge between the systems, or under what conditions responses should converge. An alternative explanation for the apparent discrepancy between the measures could be found in the unique sources of measurement error in each of the measures used in the current study (see Beckers et al., 2013). For instance, US expectancy ratings may be subjected to demand characteristics (Boddez et al., 2013), while physiological measures are characterized by high individual variability (e.g., Lykken & Venables, 1971) and specific non-associative learning changes (e.g., habituation).

In conclusion, the present study confirms previous observations of higher-order categorical fear generalization within a fear conditioning framework (Bennett et al., 2015; Dunsmoor et al., 2012; Wong & Lovibond, 2020b). Furthermore, the current study confirms a typical asymmetry in generalization in a fear conditioning paradigm (Dunsmoor & Murphy, 2014). A crucial finding is that no trait anxiety effect was observed on fear generalization when the threat ambiguity of the GS+ exemplars was low (i.e., typical condition). In contrast, high trait anxious individuals showed stronger generalization than low trait anxious individuals when the test exemplars were high in threat ambiguity (i.e., atypical condition), consistent with the principle that individuals at risk show maladaptive threat appraisal in 'weak' situations (Beckers et al., 2013; Lissek et al., 2006). As a result of this threat appraisal bias in the 'weak' atypical condition in the high trait anxious individuals, typicality asymmetry in fear generalization was restricted to the low trait anxious individuals. In terms of clinical implications, the current findings suggest that high trait anxious individuals are more likely to exhibit broader fear generalization after an atypical, rare traumatic events than low trait anxious individuals, thus yielding a higher chance to develop clinical anxiety. This finding suggests a specific pathway of how trait anxious individuals are more likely to develop clinical anxiety after trauma exposure.

CRediT authorship contribution statement

Alex H.K. Wong: Conceptualization, Methodology, Software, Formal analysis, Investigation, Writing - original draft, Visualization, Funding acquisition. **Tom Beckers:** Methodology, Resources, Writing - review & editing, Supervision, Funding acquisition.

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Appendix A. Supplementary data

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